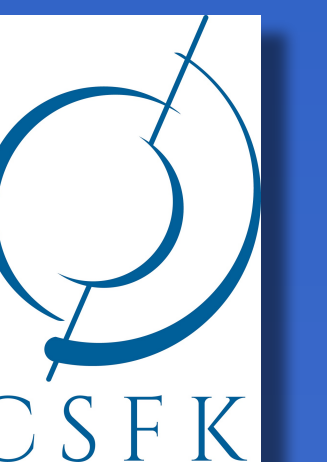




# The extreme Centaur 2013 AZ<sub>60</sub>

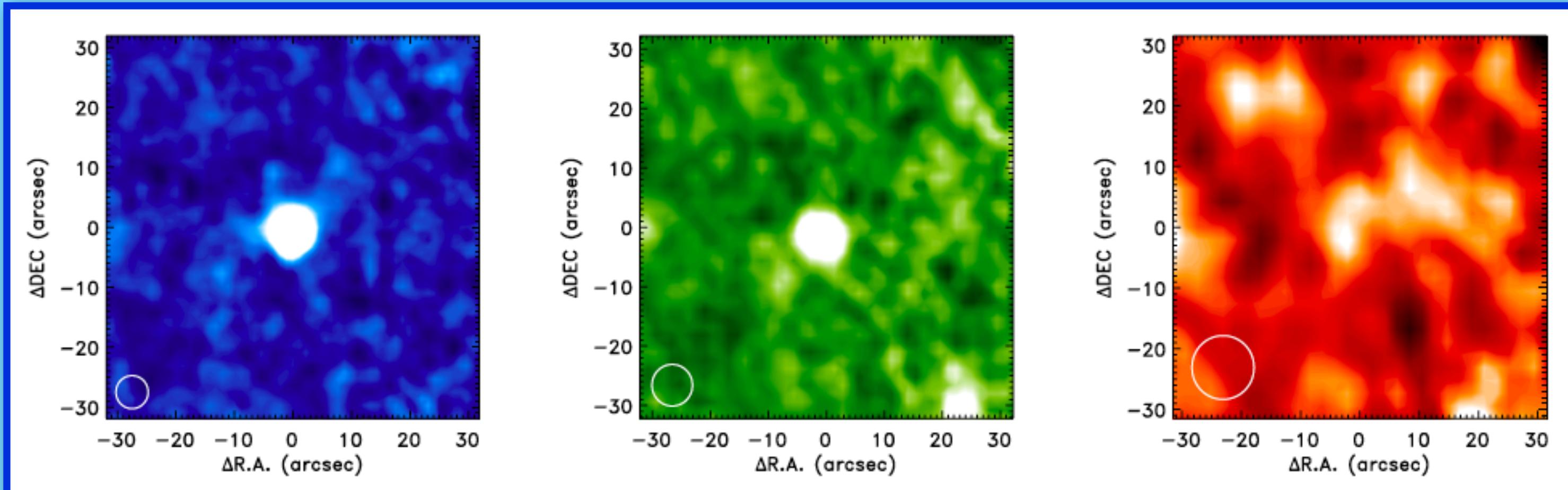


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## Abstract

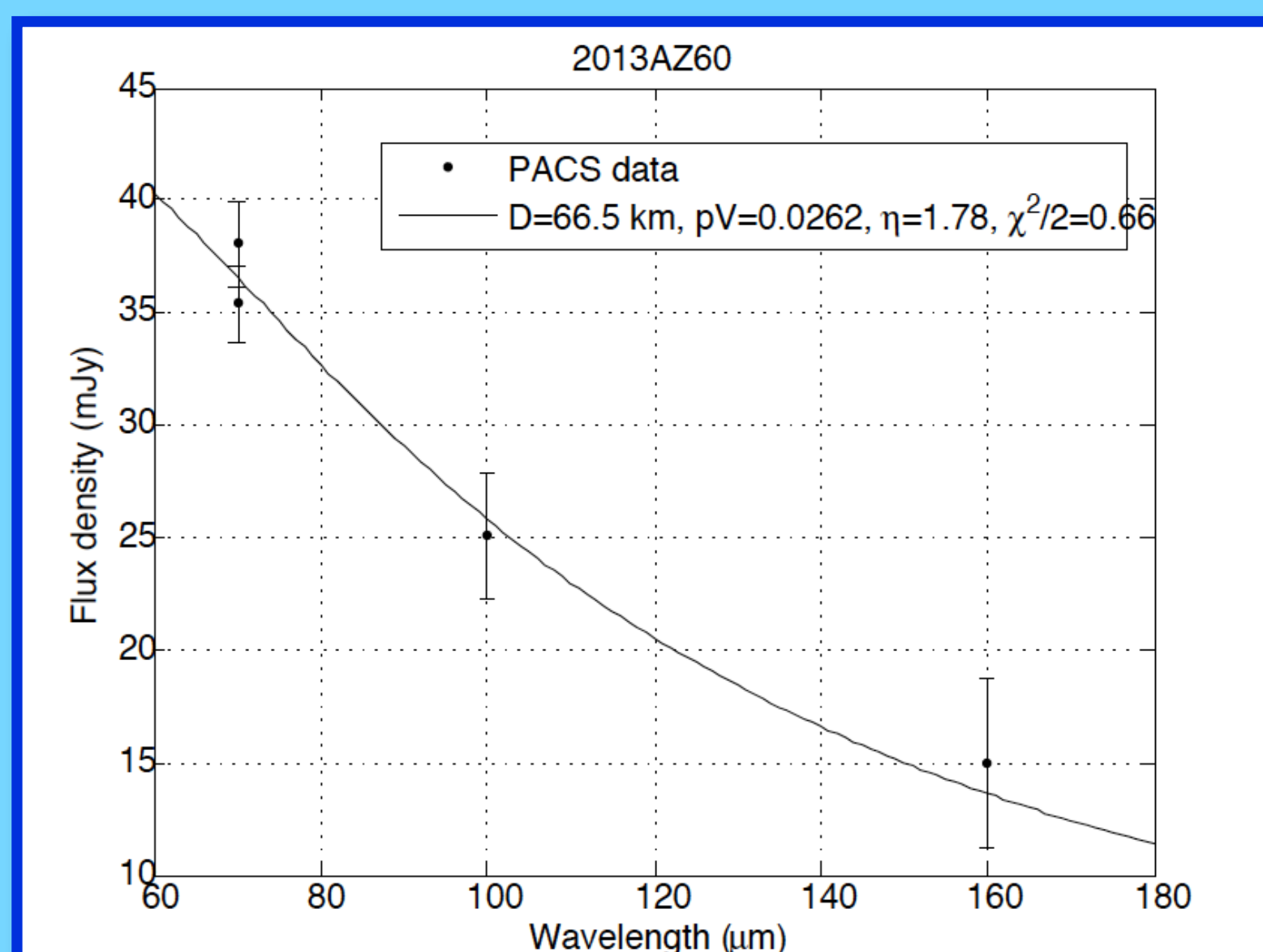
2013 AZ<sub>60</sub> is an extreme Centaur moving on a highly eccentric orbit of  $e = 0.9922$ , with a semi-major axis of 1021.09 au, and a perihelion distance of 7.91 au. 2013 AZ<sub>60</sub> was observed with the PACS camera of the Herschel Space Observatory, and we were able to derive an effective size of  $D=66.5\pm3.7$  km and a geometric albedo of  $p_V = 0.026 \pm 0.003$ . Photometric measurements revealed a low-amplitude light curve ( $0.045\pm0.007$  mag in the  $r'$  band) with a likely full period of  $P = 9.39$  h. A dynamical analysis shows that the orbit of 2013AZ<sub>60</sub> is highly unstable, with a 50% probability the target will be ejected from the Solar System within  $\sim 700$  kyr. This high level of instability indicates that 2013AZ<sub>60</sub> may just have recently been captured to its current orbit. Investigating the total time the target could have spent at small heliocentric distances ( $< 100$  au), it seems to be likely that this has only been at most 100 to 1000 years and it has a low probability that the target could reach Earth-crossing orbits (i.e.,  $< 1$  au). As the likely origin of this target is the Oort Cloud, these together suggests a relatively unaltered, pristine surface, in contradiction with the very low albedo (2.6%) derived from the thermal infrared measurements. The low albedo and red colours rather indicates an "extinct cometary" surface.

## Herschel observations



Herschel-PACS 70um (left), 100um (middle) and 160um (right) images of 2013 AZ<sub>60</sub>

- We observed 2013AZ<sub>60</sub> with the PACS photometer of the Herschel Space Observatory at two epochs using the time of a dedicated DDT proposal (DDT\_kiss\_3) in April, 2013.

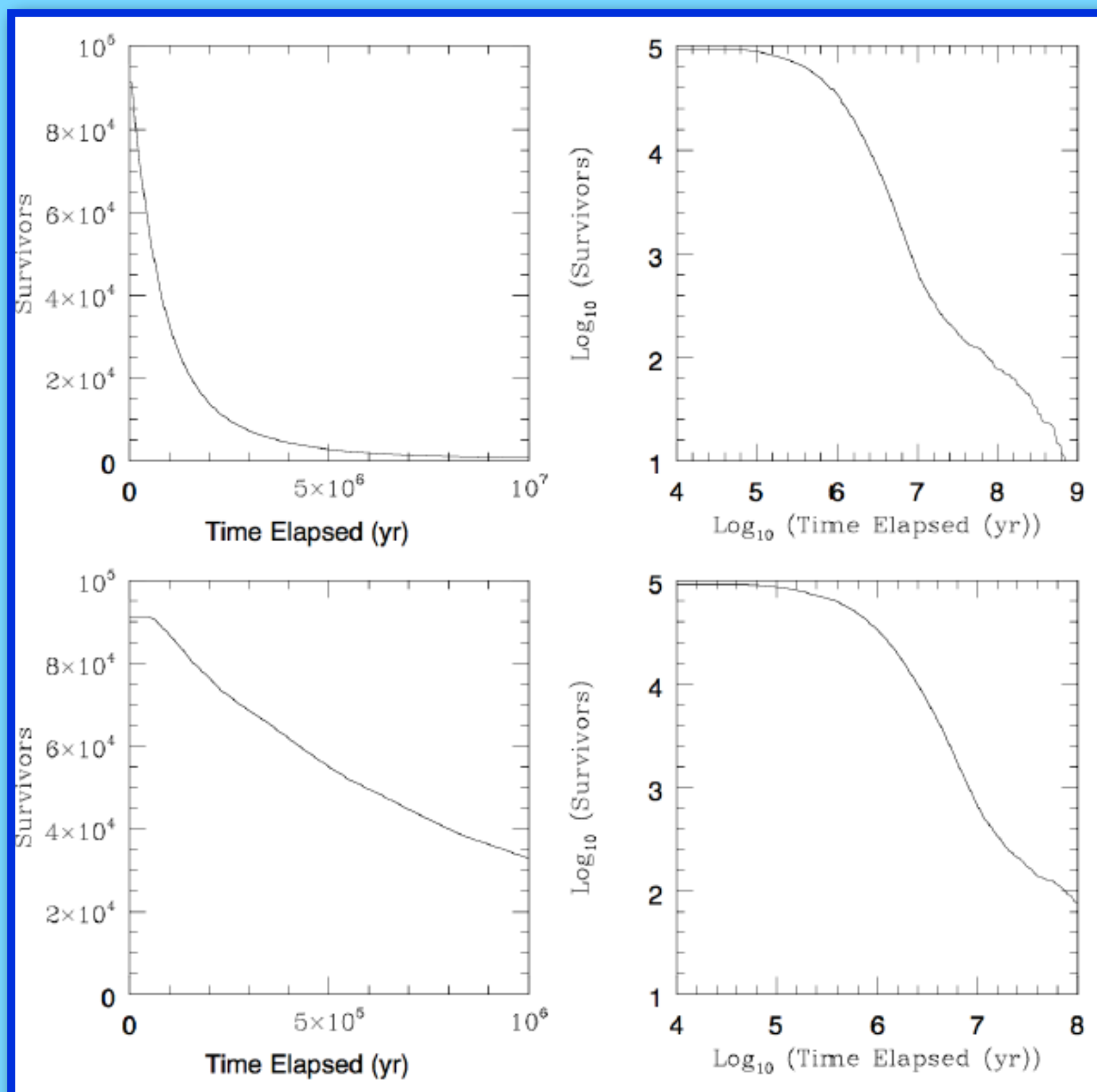


Far-infrared flux densities of 2013 AZ<sub>60</sub>, obtained with the PACS photometer of the Herschel Space Observatory. The solid line indicates the best-fit NEATM thermal emission model

- A NEATM model fit to the thermal emission of the target provides an effective diameter of  $D=66.5\pm3.7$  km and a geometric albedo of  $p_V = 0.026 \pm 0.003$  with a floating beaming parameter of  $\eta=1.78$  using  $H_V=10.46\pm0.44$ .
- Using the same input data and an assumed thermal inertia of  $\Gamma = 5 \text{ J m}^2 \text{ s}^{1/2} \text{ K}^{-1}$ , a thermophysical model (Müller & Lagerros, 2002, A&A 381, 324) provides an effective diameter of  $D=56.1\pm2.2$  km and  $p_V = 0.037\pm0.002$ , assuming an equator-on configuration.
- With a  $5\sigma$  detection limit of  $\sim 6\text{mJy}$  at  $22\mu\text{m}$  we were not able to identify the source on the Wide-field Infrared Survey Explorer (WISE) images.

## Dynamical behaviour

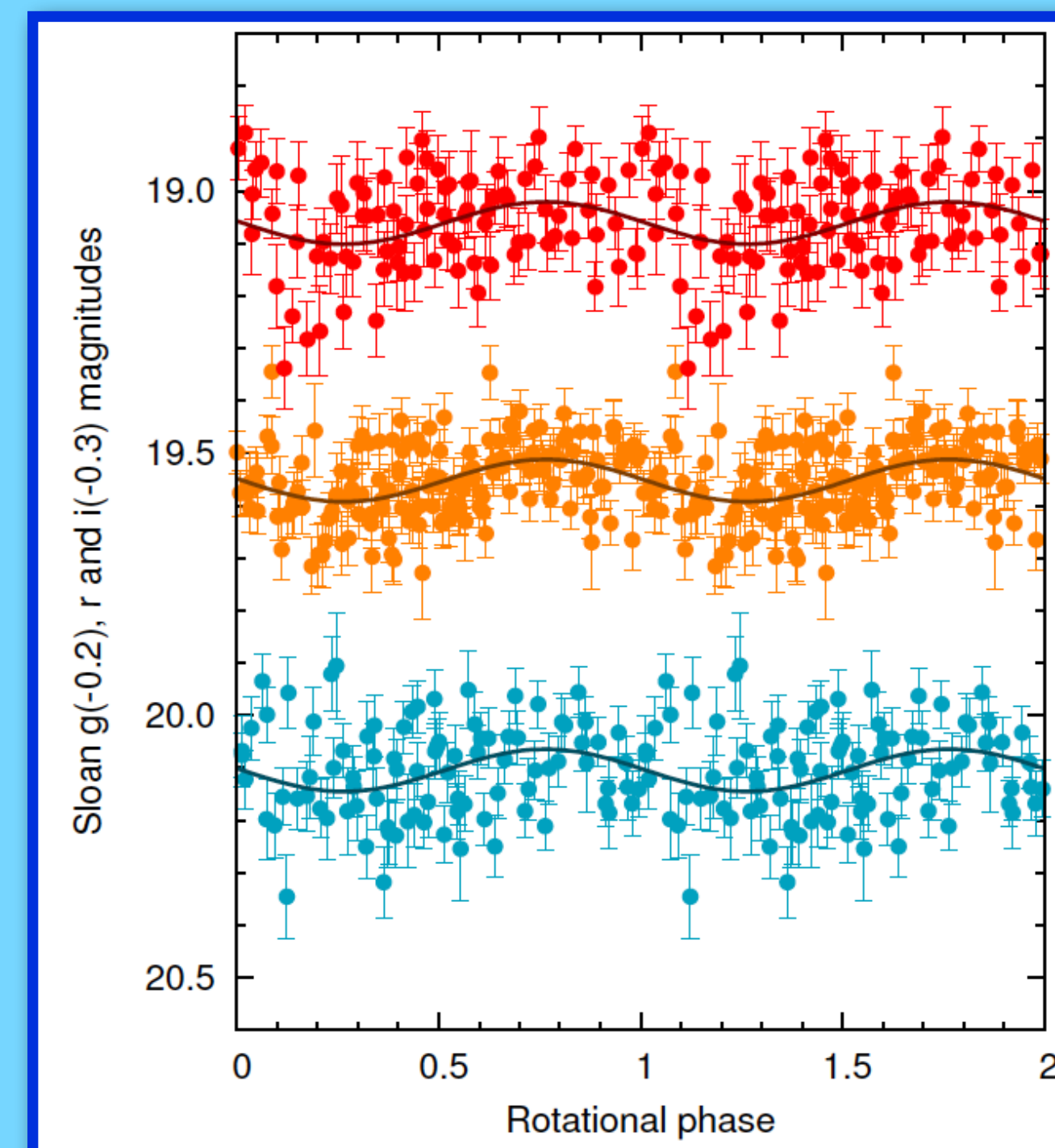
- The dynamical history is assessed by using the Hybrid integrator within the n-body dynamics package MERCURY, using  $45\times45\times45=91125$  clones, distributed uniformly in the  $\{q, e, i\}$  space
- The population of clones is highly unstable,  $\sim 64\%$  of the clones are removed in the first million years, either by ejection from the Solar System or by a collision with one of giant planets or the Sun.
- 2013 AZ<sub>60</sub> was likely recently captured into its current orbit and is likely originated from the Oort cloud.
- Two-third of the clones spent less than a thousand years within 100 au — the target is expected to have a pristine surface based on the dynamical calculations



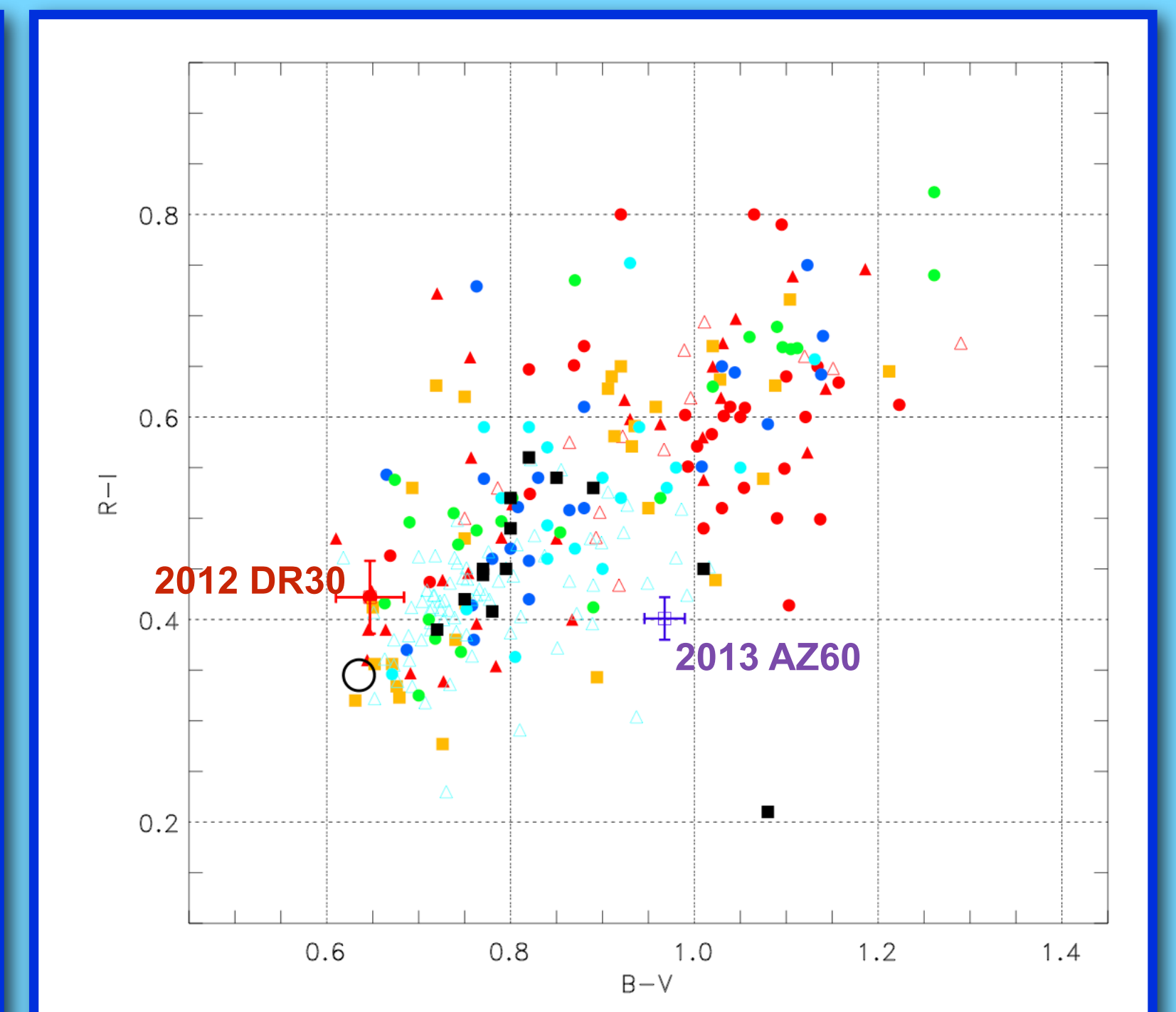
The decay of the population of 91125 clones as a function of time elapsed in our integrations.

## Visual light curve, colours and reflectance

- $g'$ ,  $r'$  and  $i'$ -band photometry was obtained with the IAC80 telescope (Teide Observatory, Tenerife) in 6 nights in November/December 2013 — these measurements also provided the light curve in these bands
- We identified a light curve period of 4.696h — the true rotation period is probably twice as long, i.e. 9.39h
- Our target has quite red colours:  $B-V=0.968\pm0.022$ ,  $V-R=0.554\pm0.022$ ,  $B-V=0.401\pm0.021$
- J, H and K-band photometry was obtained with the LIRIS instrument on the William Herschel Telescope in September, 2013.
- The NIR colours are:  $J-H=0.34\pm0.07$  and  $H-K=0.28\pm0.11$

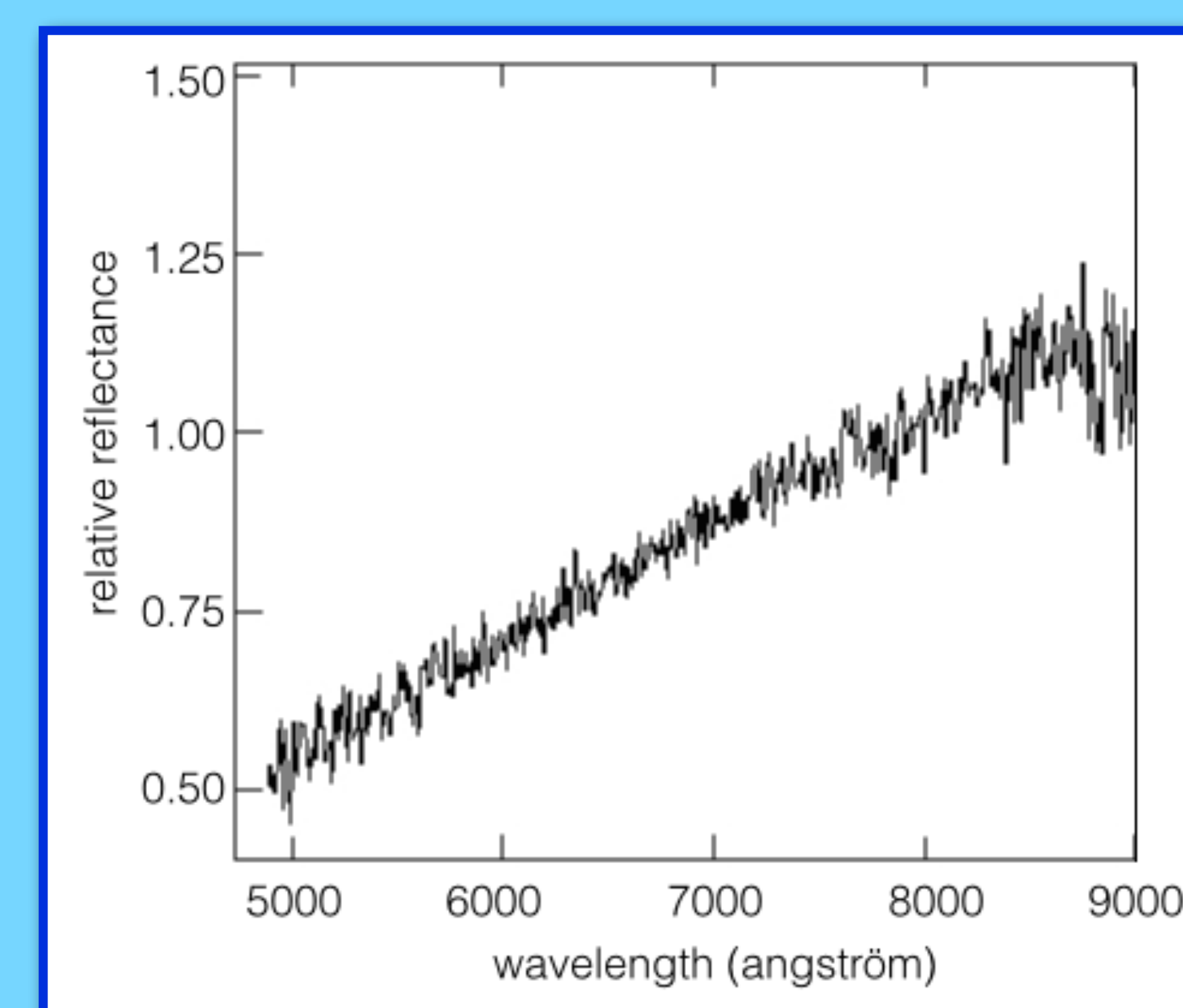


Folded optical light curves of 2013 AZ<sub>60</sub>. The folding frequency is  $n = 5.11 \text{ d}^{-1}$ .



R-I versus B-V colours of 2013 AZ<sub>60</sub> (purple cross), 2012 DR<sub>30</sub> (red cross, Kiss et al., 2013, A&A 555, A3) and other objects taken from the MBOSS2 database (Hainaut et al., 2012, A&A 546, L115). The large open circle marks the solar colours.

- Reflectance spectrum was obtained in January 2014 with the OSIRIS instrument on the Gran Telescopio CANARIAS
- The spectrum is red, in agreement with the photometric colours, and featureless up to  $\sim 900\text{nm}$ , similar to that of a D-type asteroid



Reflectance spectrum of 2013 AZ<sub>60</sub>, taken with the OSIRIS spectrometer on the GTC in January, 2014.

## Conclusions

- 2013 AZ<sub>60</sub> is very different from 2012 DR<sub>30</sub>, a Centaur previously identified in a similarly eccentric and high semi-major axis orbit (Kiss et al., 2013, A&A 555, A3)
- The surface of 2013 AZ<sub>60</sub> is much redder and much darker than that of 2012 DR<sub>30</sub> — 2013 AZ<sub>60</sub> could be an "extinct comet"
- 2013 AZ<sub>60</sub> would fit into the group of Damocloids (Jewitt, 2005, AJ, 129, 530) based on its colours, dark surface and eccentric orbit, but its Tisserand-parameter ( $T_J=3.3$ ) is quite different from that of this group ( $T_J<2$ )
- Signs of activity (outgassing) may still be expected near to its perihelion in November 2014 ( $q=7.91$  au)